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COMPUTERIZED ACCOMMODATED PERCENTAGE EVALUATION: REVIEW AND PROSPECTUS

(AIRTASK A62763N/WF55.525.403)

By

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31 December 1976

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PACIFIC MISSILE TEST CENTER

Point Mugu, California

PACIFIC MISSILE TEST CENTER

AN ACTIVITY OF THE NAVAL AIR SYSTEMS COMMAND

This report describes work accomplished under AIRTASK A62763N/WF55.525.403, Verification and Assessment of Design Criteria.

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This report reviews about a dozen past and current research efforts employing Monte Carlo "computerized accommodated percentage evaluation" (CAPE) models. The CAPE class of models estimate the effects of imposed limits of the accommodated proportion of a population. Most extensively used in studies of aircraft cockpit and related workplace design, the model has been applied to other areas as well. Four validation studies, five completed application investigations, and three on-going application efforts are described. Prospects for future applications are also briefly discussed.

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SUMMARY

This report reviews about a dozen past and current research efforts employing Monte Carlo "computerized accommodated percentage evaluation" (CAPE) models. The CAPE class of models estimate the effects of imposed limits of the accommodated proportion of a population. Most extensively used in studies of aircraft cockpit and related workplace design, the model has been applied to other areas as well. Four validation studies, five completed application investigations, and three on-going application efforts are described. Prospects for future applications are also briefly discussed.

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INTRODUCTION

Background

Computerized accommodated percentage evaluation (CAPE) models are of a class which estimate the effects of imposed limits on the accommodated proportion of a population. Initial interest in this class of models was sparked by the (1971 - 1976) investigations of Moroney and Smith. The investigations of Moroney and Smith demonstrate that traditional workplace design approaches result in exclusion of "surprisingly large" proportions of potential user populations. In their most comprehensive investigation, Moroney and Smith (1972) studied the empirical reduction in potential user (U.S. Naval aviators) as the result of restrictions on thirteen anthropometric features specific to cockpit designs. They found that more than 52 percent of the 1964 population, surveyed by Gifford et al (1965), would be excluded when 5th and 95th percentile critical limits were imposed and over 32 percent would be excluded when the 3rd and 98th percentile limits were imposed. Even with restrictions on only two moderately correlated variables, e.g., sitting eye height and functional reach with $r = 0.36$, the percentage excluded by conventional - 5th and 95th - percentile limits are surprising: 18 percent (cf Moroney, 1971). These results led Moroney and Smith (1972) to observe that magnitudes of accommodated proportions must be determined during design to avoid "...considerable reduction in the size of the accommodated population." The accommodation statistic is resistive to direct means of calculation, however, and Moroney and Smith were led to conclude, "Perhaps the only solution, other than test fitting the entire population, may be found in development of...models." Thus, Moroney and Smith (1972) suggested the need for CAPE models for workplace design.

Analysis of potential types of CAPE models resulted from the conclusion of Moroney and Smith (1972) and showed significant advantages for those based on Monte Carlo simulation techniques. Particular advantages, noted in the comparative review by Bittner and Moroney (1974), included both applicability to large numbers of variables and minimum requirements for data and computer storage. Additional advantages include ability to accept amalgamations of incomplete data from various sources (cf Bittner, Morrissey, and Moroney, 1975) and relative rapidity of calculations (cf, Bittner, 1975). Those advantages led to the development of a "basic" Monte Carlo CAPE model by Bittner (1974).

Since the Bittner (1974) CAPE model development, members of its class have stimulated about a dozen studies -- over half of which have been completed. These have included validations of the model for anthropometric-design studies, applications to general workplace and cockpit design studies, and design of subject sampling plan for a reach-anthropometry study. To date, applications have been largely confined to problems related to workplace design; however, application of CAPE models to general systems designs involving selection, training, and equipment design are currently being considered. Completed, on-going, and proposed applications of CAPE models are the subject of this report.

Purpose

The primary purpose of this report is to review both past and current research efforts employing Monte Carlo accommodated percentage models based upon that of Bittner (1974). A secondary purpose is to briefly consider the prospects for future applications of computerized accommodation models - particularly to "general design problems".

REVIEW

The approach of this review will be to sequentially consider: 1) validation studies of the Monte Carlo CAPE model; 2) completed investigations; and 3) currently on-going studies. Within each of these topics, consideration of studies will be historical with most recently "conceived" studies being last. This approach was selected to give historical perspective.

Validation Studies

There have been four investigations validating the CAPE models application to anthropometric exclusion studies. The first of these was described in Bittner (1974) and compared the results of a "basic" CAPE model with the empirical results obtained by Moroney and Smith (1972). Figure 1 graphically shows the successive effect of exclusions on thirteen "cockpit related" variables. Going from left to right in this figure, one can see progressive declines in the remaining user population as 3rd and 98th and 5th and 95th cutoff limits are imposed with the former showing about 32 percent remaining at the last exclusion and the latter about 53 percent. The close correspondence of empirical (solid lines) and CAPE model (symbols) is seen by their near overlap.

Similar results, to those shown in Bittner (1974), were obtained in a second study (Bittner et al, 1975). This study compared the results of a CAPE model and the RAE (1974) empirical exclusion study of the effects of 3rd-to-99th accommodation ranges as exclusions on eight variables are successively applied. The RAE (1974) study was based on an earlier survey of 2000 RAF aircrew by Boulton et al (1973). Figure 2 is similar to figure 1 and outlines the effects as exclusions are successively applied. The empirical (solid line) and model (symbols) virtually overlap with deviation most detectable at the termination of the exclusions where the model shows 20 percent and the empirical results are seen to be about 21 percent.

The third validation study was described in Bittner and Halcomb (1976) and compared a CAPE model with empirical results described in Roebuck et al (1975). The Roebuck et al empirical study examined the effects of 5th-to-95th, 5th-to-75th, and 5th-to-50th percentile accommodation ranges as exclusions on 15 cockpit related variables were successively applied. Their population was a 1000 member subsample of the 1950 U.S. Air Force survey of flight personnel reported by Hertzberg et al (1954). Results of the Roebuck et al study are shown in figure 3 (as solid lines) together with results of CAPE model evaluations (symbols). Here a significant deviation of model and empirical results is seen for the 5th-to-95th percentile graph with the divergence largest at termination. Possible explanations which could fully account for this divergence by the "nature of the data" are offered in Bittner and Halcomb. These will not be discussed here as the largest deviation represents a small relative error: about 10 percent. As a whole the CAPE model and empirical results can be seen to be relatively close in this study.

The fourth validation study was described by Morrissey et al (1976) and compared a CAPE model with empirical results described by Daniels (1952). The Daniels' study examined the effects of an approximate 35th-to-65th percentile range as exclusions were successively applied on ten "clothing design" variables. The Daniels' study utilized the entire 4063 sample from the 1950 USAF (Hertzberg et al, 1954) survey. Results of the Daniels' study are shown in figure 4 (solid line) together with the results of a CAPE model evaluation (triangles). Examining this figure, it can be seen that the model and empirical results nearly overlap ($\underline{r} \cong 0.999$). The Daniels' (1952) study is unique among exclusion studies as it has the largest sample base and the clearest description of actual (vs. theoretical) accommodation ranges. These unique characteristics resulted in the "most powerful" test of the CAPE model to date -- a test where the model virtually over-lays the empirical results.

In concluding discussion of Monte Carlo model validation studies, it is noteworthy that the apparent correlations seen in figures 1 to 4 are confirmed by statistical measure. Pearson correlations ($\underline{r}$) ranged from 0.996 to more than 0.999 over the seven model-empirical comparisons.

<u>Completed Application Studies</u>

There have been five applications of the CAPE Monte Carlo model completed to date. They have been concerned with a variety of topics including: 1) selection of cockpit design limits; 2) accommodation of females in a workspace designed to male standards; 3) development and application of a hybrid (Monte-Carlo/link-man) model for cockpit analysis; 4) development of basic workplace (seat-console) design criteria; and 5) development of sampling plans for anthropometrically related studies. Each of these applications will be taken up in turn below.

<u>Cockpit Design Limits</u>

In addition to validating the CAPE model, Bittner et al (1975) studied the percentage of pilots that would be excluded if 3rd and/or 98th versus 5th and/or 95th percentile limits were applied to ten anthropometric dimensions critical to a proposed aircraft (AV-16A). Their analysis was <u>selective</u> with restrictions being made either a) only at the lower extreme; b) at both lower and upper extremes; or c) only at the upper extreme. This rationale rested on the fact that not all small anthropometric features (e.g., buttock-knee length) necessarily interfere with mission safety and some large features (e.g., functional reach) are advantageous. Variables and ranges excluded (with a, b, and c as above) were: 1) Sitting Height (b); 2) Buttock-Knee Length (c); 3) Buttock-Heel Length (b); 4) Functional Reach (a); 5) Shoulder Breadth (c); 6) Hip Breadth (c); 7) Thigh Depth (c); 8) Stomach Depth (c); 9) Eye Height, Sitting (b); and 10) Shoulder Height, Sitting (c). The results of this study indicated that with 5th and/or 95th percentile limits, 33.9 percent of the potential population would be excluded versus 19.8 percent with 3rd and/or 98th percentile limits.

<u>Accommodation of a Female Population</u>

Ketcham et al (1976) made a study of anthropometric accommodation of a female population in a workplace designed to male standards. Their investigation was motivated by a report by Lane (1974) who attempted to estimate the proportion of women excluded by current (male-orientated) fighter aircraft designs. Hampered by lack of a method for examining more than unidimensional exclusions, Lane estimated that at least 65 percent would be excluded and up to 80 - 85 percent might be excluded under the full impact of multivariate exclusions. Ketcham et al, using CAPE to estimate multivariate effects, substantiated Lane's estimation by applying 2nd and 98th percentile male (Gifford et al, 1965) accommodation ranges to a female (Clauser et al, 1972) population. Figure 5 illustrates the impact of eight successive cockpit-related restrictions on a female population (broken line) and, for comparison, on a male population (solid line). This figure shows that for all eight variables, 22 percent of the male and about 90 percent of the female populations would be excluded.

Ketcham et al (1976), it is noteworthy, report several workplace related variables missing from the female anthropometric surveys they examined. This motivated their study of the effects of applying male cutoffs to a "female-sized" population with male feature interrelations (correlations). The close fit of the hybrid (females-male matrix) and female population results can also be seen in figure 4 where the hybrid (circles) overlay the female (broken line) values. The closeness of this fit ($\underline{r}$ 0.999) suggests that "reasonable substitutions" of male anthropometric relationships can be made where other data are not available. Because console and workplace designs of many standards and guides (e.g., DoD, 1974 and Hertzberg, 1972) are based on male survey data, such substitutions may be necessary to meet the pressing needs to accommodate women in the military (cf Grace, 1975) and civilian jobs. Certainly the Ketcham et al (1976) suggestions for study of differential male and female design criteria should be pursued.

Hybrid CAPE/Link-Man/Cockpit Model

The possibility of a hybridized CAPE/Link-Man/Workplace model was proposed by Bittner and Moroney (1974). Limitations encountered in (AV-16A) cockpit analysis, however, led Bittner et al (1975) to detail a staged proposal. This proposal led to the development of a CAPE cockpit analysis model by Bittner (1975).

The cockpit analysis CAPE model consists of an advanced Monte Carlo component for generating anthropometric features of sample subjects, a link-man component to integrate features, and a basic cockpit description component. Figure 6 depicts the pilot link system and can be characterized as having: 1) design eye position (DEP), "grip" and leg (link) reach models described in DoD (1969); and 2) a single link (fused) spine parallel to the seat back angle (SBA). The horizontal and vertical positions of the DEP generated by the model, it is noteworthy, are close (for SBA 22°) to empirical results for 15 subjects reported by Richardson (1975) with a reduction in DEP to seat back distance resulting in enhanced fit (cf Bittner, 1975). The total cockpit model can be used for accommodation studies of cockpits as shown in table 1. Here the results of successive test sequences for 18 checks are shown for four hypothetical cockpits: A, B, C, and D. Successive checks include those for "head clearance," "seat adjustments," "ejection (knee) clearance," "right hand reaches," "left hand reaches," and "pedal adjustments." Going from cockpit A to D, it is noteworthy, each cockpit represents a modification of the cockpit to the left. Cockpit B is A with more headroom, C is B with controls moved toward the pilot, and cockpit D is C with more ejection (knee) clearance. The "evolution" of cockpits, illustrated by this table, is more fully discussed in Bittner (1975), but the potential utility of the hybrid model during design and evaluation of cockpits is obvious. The CAPE model for cockpit analysis, although new, has been used to make an "anthropometric check of a proposed fighter" (Ketcham, 1976).

Workplace Design Criteria

Bittner et al (1976) have demonstrated the application of a general workplace (seat-console) CAPE model "...to insure accommodation of approximately 90 percent of a user population." Their study was motivated by new requirements given in MIL-STD-1472B (DoD, 1974), a United States military human engineering standard. This standard requires that "where two or more dimensions are used simultaneously as design parameters, the central 90 percent of the total user population must be accommodated" (DoD, 1974, p99).

The Bittner et al (1976) demonstration examined a seat-console design which was "sit-only," required "no vision over top," and "minimum torso turning." Using a conservative "selective restrictions" (similar to those in the above "cockpit design limits"), they found the results shown in figure 7. It can be seen by examining this figure that to insure only 10 percent exclusion, selective restrictions for tails of individual dimensions must be less than 1.75 percent, i.e., with design restrictions of 1.75th or 98.25th percentiles. These limits are too lenient for seat-console designs with additional requirements, e.g., vision over top, increased operator mobility, etc. Likewise in designs where some design features are fixed (i.e., with many "standard designs"), non-fixed variables would require wider limits of accommodation. This led Bittner et al to detail a CAPE model and analysis procedure applicable to other more general seat-console designs. Where such modeling is not possible, Bittner et al (1976) conclude that adoption of at least the 1.75th and 98.25th percentile limits would provide immediate improvement toward the goal of 90 percent accommodation.

Anthropometric Sampling Plans

In an unpublished study at Texas Tech University (TTU), a CAPE model was used in the development of two height-weight sampling plans for respectively 25 males and 25 females. The object of the plans was to match means, standard deviations, and correlations with the respective Clauser et al (1972) female and Gifford et al (1965) male surveys. The approach was to divide the ranges of both height and weight into five equal percentile ranges: 1) 0-20th; 2) 20th-40th; 3) 40th-60th; and 5) 80th-100th. This resulted in a five by five (25 cell) array that would contain exactly one entry per cell <u>if</u> the correlation between height and weight were zero. Appropriate proportions for a target correlation were determined using 100 to 400 sample runs of the Bittner (1974) model. The result is shown in table 2 where cells were rounded to half subjects. (For flexibility, experimenters were allowed to round up or down a particular cell if an adjacent cell was correspondingly rounded up or down.) Separate male and female plans were prepared from table 2 by replacing, with the exception of the 0th and 100th, all percentile values with the corresponding Gifford et al and Clauser et al surveyed values. The 0th and 100th percentile values were replaced with the limiting 0.5th and 99.5th values. The effectiveness of these plans can be seen by comparing the results of samples of 25 male and female psychology students with those given in Gifford et al and Clauser et al. These comparisons are shown in table 3 where the results look reasonable considering the small samples and target (0.5) correlation. Compared against other studies (e.g., Thordsen et al (1972) with 51 subjects), the errors in means and standard deviations appear to be of average or smaller magnitude. Thus the effectiveness of the plan for small samples is comparable to that obtained by other methods.

Current Application Integrations

Three applications of the CAPE Monte Carlo model are currently in progress. These include: 1) study of "multidimensional percentile men mannequins;" 2) the Boeing "crewstation assessment of reach (CAR) model;" and 3) study of "percentile reach surfaces." Each of these will be taken up in turn below.

Multidimensional Percentile Men Mannequins

As noted in the introduction, Moroney and Smith (1972) concluded that perhaps "test fitting" and "models" were the only methods for assuring accommodation in design. An extension of the conventional percentile template-mannequin approach, however, was suggested in discussions between J. M. Stroud, W. F. Moroney, and this author late in 1973. This suggestion was based on the conceptualization of the distribution of anthropometric features as approximately 2-to-5 dimentional normal. Under this conceptualization hyper-elipsoids could be developed which contained specific proportions (e.g., 95 percent) of subject populations (cf Anderson, 1958 p108). Selecting representative mannequins at the centroid and axes of such a surface, it was conjectured, would provide an economical method of characterizing the population contained within the elipsoid. Hence, using a three or four dimensional approximation, respective sets of 9 or 17 mannequins could characterize any specified proportion of a population.

To test the feasibility of such an approach, three and four factor approximations of the distribution of anthropometric features were developed by principle axis analysis. The Moroney and Smith (1972) 13 cockpit related feature intercorrelation matrix was the input to this analysis. The approximations were derived from the respective three and four factor matrices by "normalizing" the factor weights so that the respective approximate correlation matrices would have ones along the diagonal. The resulting three and four dimensional models were then compared, using the Bittner (1974) CAPE program, with theoretical one and empirical 13 dimensional results. Figure 8 shows the results of 2.5th-to-97.5th and 5th-to-95th percentile accommodation ranges on the proportions of population accommodated for varing dimensionality. It is seen that the simplified models underestimate non-accommodation by about a third for three factors and about a sixth for four factors. The three and four dimensional models, however, are seen to be vastly superior to the one dimensional model. Conventional large, medium, and small percentile mannequins can be viewed as special cases of the one dimensional model; hence, the development of 3 - 4 dimensional mannequins shows considerable promise as design tools. Development of such mannequins is currently under way at TTU.

Boeing CAR Model

The Boeing "crewstation assessment of reach (CAR)" model was an outgrowth of discussions with U.S. Navy personnel concerning the development of a hybrid link-accommodation model (cf Bittner et al, 1975 App. C). Like the earlier described Bittner (1975) hybrid model, the CAR model is a combination link-man and Monte Carlo model (Chen and Renshaw, 1976). The Monte Carlo component of the CAR model, it is noteworthy, is an essentially unmodified version of that developed by Bittner (1975). The CAR link-man, however, is a modification of the BOEMAN model described by Ryan (1970). Modifications to the link-man include addition of a third link in the hand to provide for a full range of reach/grips, restrictions on some angular limits on the arm which result in essentially a "vector" reach, and addition of a head-helmet link to provide for an over the head clearance check. Modifications to the program provide for user interactive mode input and rapid calculation of results (both are considerable improvements over the previous BOEMAN versions). The CAR model, because it is related to the (Ryan, 1970) BOEMAN, has potential applications to workplaces not considered by the current Bittner (1975) CAPE model. The CAR model, in particular, can consider non-restrained reaches and (potentially) obstruction problems of limbs and workplace surfaces or limbs and vision. The Bittner (1975) model, on the other hand, has the advantages of clearance-adjustment checks (e.g., buttock-to-knee) not considered by the current CAR model. Full documentation of the CAR model is given in Chen et al (1976 a and b).

Percentile Reach Surface

Boundaries for operator reaches have been the object of several studies (e.g., Kennedy, 1964; Laubach and Alexander, 1972). The results of these studies vary in form, but common results are boundaries whose points can each be reached by a fixed percentage of users (e.g., 95 percent) Such boundaries are useful when the object is to assure that one control - placed at a point on the boundary - can be reached by a fixed proportion of the population. Such boundaries are not useful when one wants to assure the two or more controls (points) will be reachable by a fixed proportion of a population. This is because somewhat separate portions of a population are accommodated at separate points. What is needed is a method for assuring that all points of interest can be reached by a fixed proportion of the user population.

Obviously the problem is one where a CAPE model would be useful (Ayoub et al, 1975). Using exclusion limits relative to a design point (e.g., seat reference point), one could test the joint accommodation for two or more controls (points). However, the application of such a model to a large number of finely spaced points could be used to produce a surface where all points could be reached by a fixed proportion of a user population, i.e., a percentile reach surface. Current study at TTU has proceeded to the identification of modifications to the Bittner (1974) CAPE model needed to analyze several hundred surface points. Ultimately, this work will result in the development of reach surfaces.

PROSPECTUS

CAPE models, as noted in the earlier review, initially were developed for "static" anthropometric dimensions and have only recently been extended to a dynamic variable - reach. It has been suggested that CAPE models could be extended to other dynamic variables (e.g., strength) and to another class of variables - viz., psychological. Rationale for these extensions will be considered below.

Physical Models

In a workplace, the fullness of user population "physical" diversity - critical to completion of its purpose - must be provided. The designer of a fighter aircraft, for example, must provide for accommodation of static anthropometric differences (e.g., sitting-eye-height), reach differences (e.g., control placement), and strength differences (e.g., ejection pull requirements). "Physical" variables, such as these, interact and must be jointly considered if user accommodation is to be maximized. Reduction in the space available for accommodating tall pilots, for example, will reduce both the average reach and strength capabilities of the accommodated portion of the user population. Hence a combined - anthropometric, reach and strength - model is required if fuller potential user accommodation is to be realized.

Recent investigations, all with threads of common anthropometric variables, make possible the weaving together of a physical CAPE model. Straight forward methods for approximation of a joint covariance or correlation matrix from disparate matrices with common variables can be derived from results given in Anderson (1958). Combining the reach results of Laubach and Alexander (1971), the strength results of Thordsen et al (1972), the anthropometric results of Gifford et al (1964), and recent supinating seat results Deivanayagam (1976) would result in a total physical cockpit CAPE model. For aircraft cockpits and related workplaces, at least, the prospects for near-future development of a physical CAPE model are excellent.

Psychological Models

The function of workplaces is frequently more than physical in nature - "mental work" may be the major task of its users. Cognitive and noncognitive psychological factors are primary determiners of the effectiveness of mental work and are distributed unevenly within potential user populations. Lack of psychological accommodation by a design can be just as disastrous as lack of physical accommodation. This suggests study of CAPE models for psychological variables. Surprisingly, the psychological testing literature contains references to "cutting score" selection techniques and accommodation estimation problems (cf. Thorndike, 1949). However, with exceptions where large bodies of data make "test fitting" applicable as in studies reported in Barnette (1964), models have been bivariate or trivariate. General multivariate models such as the CAPE models appear to have not been applied. The current CAPE models, therefore, offer an opportunity for application to both workplace and selection procedure design. With the bulk of multidimensional data reported in the psychological literature, prospects for preliminary modeling studies of both sorts appear to be good.

Combined Physical-Psychological Models

The prospects for physical and psychological accommodation models have been independently discussed above. The designer of a workplace, however, faces both types of variables and not infrequently must make trade-offs of the two types of variables. With a combined physical-psychological model, the impact of such trade-offs on accommodation could be fully considered. Such a combined model - in long term projections - also would permit system analyst to trade off selection of personnel, training type/kind, and equipment design. Such models await future effort, but the prospects for their utility appear good.

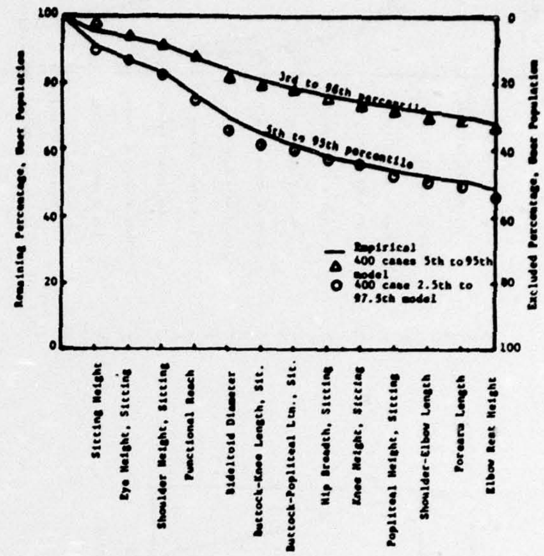

Figure 1. Graphical Comparison of Bittner (1974) CAPE Model and Moroney and Smith (1972) Empirical Results.

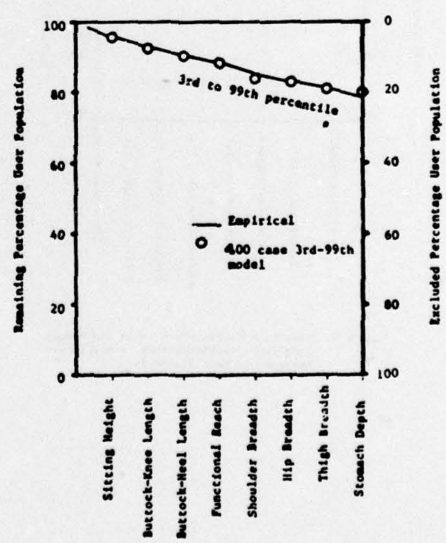

Figure 2. Graphical Comparison of Bittner et al (1975) and RAE (1974) Empirical Results.

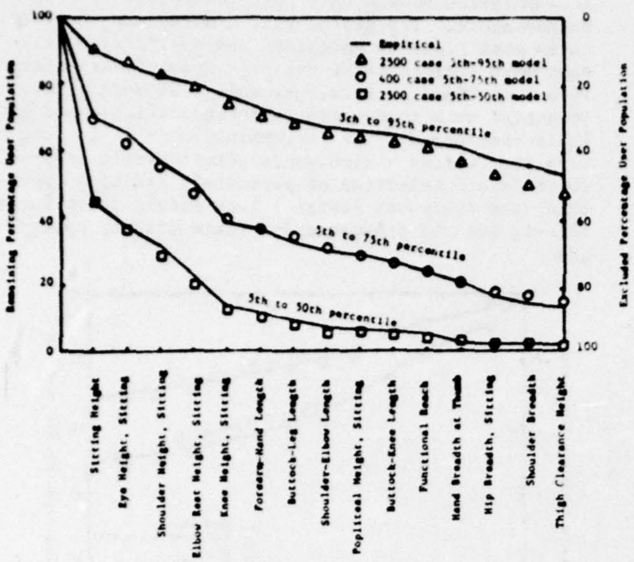

Figure 3. Graphical Comparison of Bittner and Halcomb (1976) CAPE Model and Roebuck et al (1975) Empirical Results.

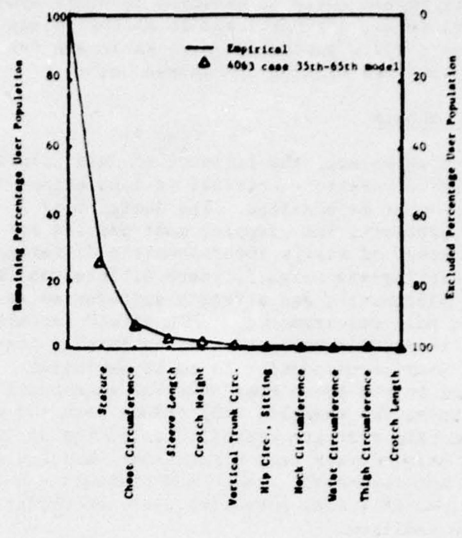

Figure 4. Graphical Comparison of Morrissey et al (1976) CAPE model and Daniels (1952) Empirical Results

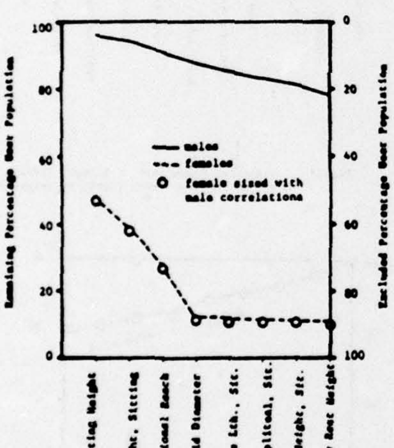

Figure 5. Graphical Comparison of Male and Female Population Accommodations in A Workplace Designed to Male Standards.

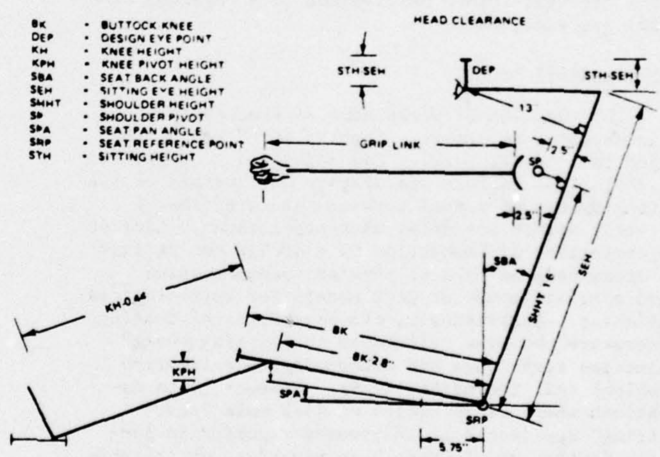

Figure 6. Pilot Link System Model

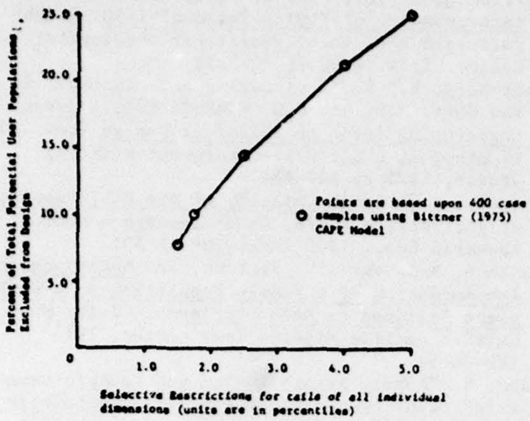

Figure 7. Demonstration of Accommodated Percentage Workplace Analysis: Sit-Only No-Vision Over Console with Minimum Torso Turning Required (Bittner et al, 1976).

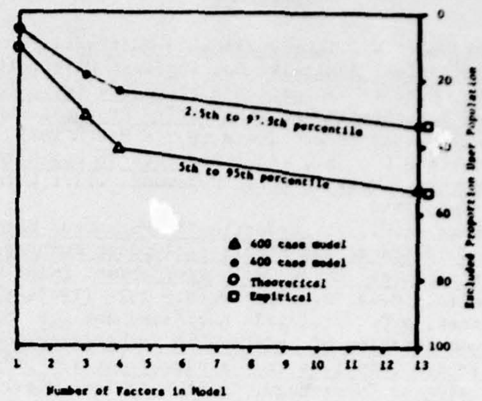

Figure 8. Comparison of Empirical, Theoretical, and CAPE Model Results for Different Numbers of Factrr

Table 1. Comparison of Percert Excluded by Various Hypothetical Cockpit Designs**

Test Sequence	Criteria	Successive Percent Exclude			
		Cockpit A	Cockpit B	Cockpit C	Cockpit D
1	Head Clearance	97.75	1.25*	1.25	1.25
2	Seat Adj.-Upper	97.75	14.5	14.5	14.5
3	Seat Adj.-Lower	97.75	14.5	14.5	14.5
4	Eject Clear	98.75	52.25	52.25	16.75*
5	Rt Rch #1	100.0	99.25	65.25*	32.25
6	Rt Rch #2	100.0	100.0	96.25*	87.25
7	Rt Rch #3	100.0	100.0	96.25*	87.25
8	Rt Rch #4	100.0	100.0	96.25*	87.25
9	Lt Rch #1	100.0	100.0	96.25*	87.25
10	Lt Rch #2	100.0	100.0	96.25*	87.25
11	Lt Rch #3	100.0	100.0	96.25*	87.25
12	Lt Rch #4	100.0	100.0	96.25*	87.25
13	Lt Rch #5	100.0	100.0	96.25*	87.25
14	Lt Rch #6	100.0	100.0	96.25*	87.25
15	Lt Rch #7	100.0	100.0	96.25*	87.25
16	Lt Rch #8	100.0	100.0	96.25*	87.25
17	Pedal Adj. Fwd.	100.0	100.0	96.25	89.75
18	Pedal Adj. Aft	100.0	100.0	96.5	90.00

* Parameter Changed from Previous Cockpit.
** Adapted from Bittner (1975).

Table 2. General Height-Weight Stratefied Sample Plan

Weight in Percentiles	0–20	20–40	40–60	60–80	80–100
80–100	0	1/2	1/2	1-1/2	2-1/2
60–80	1/2	1	1	1	1-1/2
40–60	1/2	1	2	1	1/2
20–40	1-1/2	1	1	1	1/2
0–20	2-1/2	1-1/2	1/2	1/2	0

Height in Percentiles

Table 3. Characteristics of the Study Sample as Compared with Target Populations.

		FEMALES		MALES	
		Obs.		Obs.	
Height	$\bar{X}$*	163.8cm	162.1cm	177.4cm	177.6cm
	s**	4.1cm	6.0cm	6.2cm	5.9cm
Weight	$\bar{X}$	56.6Kg	57.7Kg	76.8Kg	77.7Kg
	s	6.5Kg	7.5Kg	10.4Kg	8.7Kg
	r***	0.55	0.53	0.56	0.45

* Mean
** Standard Deviation
*** Pearson Correlations

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